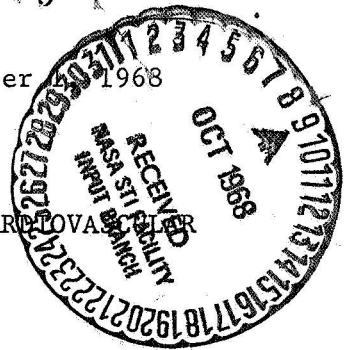


Mayo Assoc.



STUDIES OF THE EFFECTS OF GRAVITATIONAL AND INERTIAL FORCES ON CARDIOVASCULAR AND RESPIRATORY DYNAMICS

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This report will summarize the progress made in investigative projects receiving support from this grant during the period October 1, 1967 to the present.

I. Development of biplane roentgen videometry for dynamic studies of the size and shape of cardiac chambers

Two fluoroscopic image-intensifier video systems mounted at right angles to each other, plus special switching and delay circuits are used to display and record biplane images in the same video field (Figures 1 and 2). Dimensions are obtained by measuring the traversal time of the horizontal scans of the video beam between specific points (e.g., the heart borders) on the video picture.

The technic for detection of the borders of the roentgen fluoroscopic televised biplane images of the left ventricle has been outlined in the text and figures of the April 1, 1968 status report and, therefore, will not be repeated herein.

Biplane dimensions of successive horizontal scans are converted to cross-sectional areas by the computer and the areas for all of the more than sixty cross sections encompassing the heart summed to compute a volume after each vertical scan of the video field. The field repetition rate of the video system of sixty per second determines the sampling rate of the system. A flying-spot scanner optical electronic system which, under interactive operator control, allows gating of the video signal to the specific areas encompassing the two cardiac silhouettes, plus continuously variable manual shading of the background levels on which the cardiac projections are superimposed followed by electronic brightening of the video beam at the recognition points of the cardiac borders, has

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been designed and tested (Figures 2 to 4). The system allows a continuous video display of single video fields so that the precision of the superposition of the circumferential recognition points for the complete cardiac borders in each plane for any selected biplane video field can be examined during the "stop action" mode of video replay using a specially adapted video disc assembly. The electronic and manual shading of the background signal can then be adjusted by the operator on an interactive basis to obtain the optimum possible degree of concurrence of the actual borders and the recognition points circumscribing these borders. These adjustments are optimized for the particular video fields associated with the end-diastolic and end-systolic points in the cardiac cycle determined from simultaneous recordings of the ventricular pressure pulse on the same videotape.

The two-dimensional cross-sectional data are inputted to the 3200 computer via a 20-megacycle clock, four 10-bit counter assembly. The computed values of ventricular volume will be displayed at 1/60th of a second intervals along with the simultaneous intraventricular pressure values.

Computer controlled methods for two- and three-dimensional dynamic and stop motion displays of these data are being investigated in cooperation with Doctors Homer Warner and David Evans of the University of Utah.

It is anticipated that these new roentgen television techniques will provide a degree of power for quantitative studies of hemodynamic processes in closed-chest animals and man which has been heretofore unattainable.

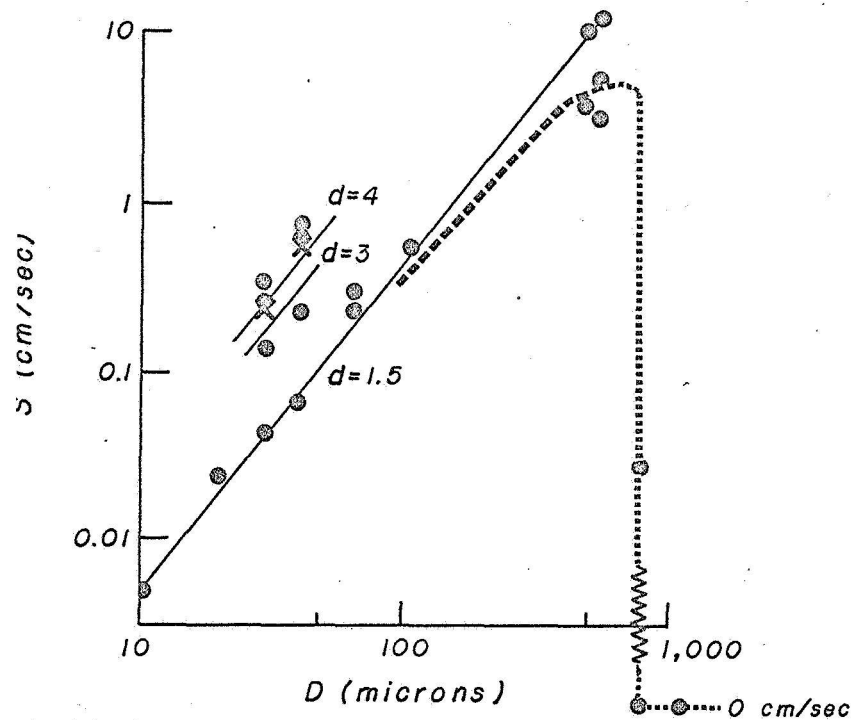
II. Other projects designed to elucidate the effects of the gravitational-inertial force environment on the cardiopulmonary system

A. Hydraulic properties of the pleural space suggested by sedimentation of the type anticipated for an open fluid channel by microspheres in dogs without thoracotomy:

The structure and function of the lungs are the most susceptible organ system in the body to disruption due to changes in the gravitational-inertial force

environment. The nature of the pleural space, particularly its hydraulic and pressure transmitting characteristics, are of fundamental importance for increased understanding of the effects of the force environment on cardiopulmonary function.

SEDIMENTATION vs SPHERE SIZE



In an attempt to partially resolve the different concepts concerning the nature of pleural space (J. Appl. Physiol. 21:1500, 1966; Handbook of Physiol. III, Vol. 1, p. 403, 1964), spheres of varying density (d) were injected through narrow percutaneously inserted catheters and the sedimentation rates (S) observed by gamma emission of Yb^{169} or by roentgen videometry. Up to a sphere diameter (D) of 100 microns in the prone position, values for S complied with those predicted by Stokes' Law (solid lines) but not for D in excess of 1000 microns which preliminary optical measurements suggest may be the extreme limited width of the space

B. Regional differences in pleural and esophageal pressures in head-up and head-down positions

Vertical gradients in pleural pressure and alveolar size in transverse and head-up positions plus 100% arterial-venous shunts in the most dependent regions of the lungs during exposure to levels of accelerations similar to those encountered during the launch and re-entry phases of space flight suggest atelectasis at these sites (Aerospace Med. 38:225, 1967). Failure to find a gradient in alveolar size in the head-down position (Glazier, J. Appl. Physiol. 23:694, 1967) prompted study of intrapleural, intraesophageal, intrapericardial, right and left atrial pressures, total and regional pulmonary blood flows in anesthetized dogs studied without thoracotomy when head-up and head-down.

Simultaneous right apical and basal intrapleural pressures were recorded using percutaneously inserted, fluid-filled #4F catheters attached to P23d strain gauges in six anesthetized dogs supported successively in the head-up and head-down positions. Withdrawals of 2-3 cm of intrapleural and intraesophageal catheters with pressures and biplane roentgenograms at each step were obtained when head-down. Average pressures at the apex were -16.3 ± 1.2 (SEM) cm H_2O and -2.6 ± 0.47 as

compared to -4.6 ± 0.67 and -16.6 ± 0.81 at the base when in the head-up and head-down positions, respectively. Average vertical distances and pressure gradients between pleural catheter tips were 17.9 and 18.2 cm, and 0.66 and 0.76 ± 0.05 cm/H₂O/cm when head-up and head-down, respectively. When head-down, an approximately linear vertical gradient between apex and dome of diaphragm of 0.6 ± 0.05 cm H₂O/cm and a more variable value of 1.1 ± 0.14 between dome and costophrenic angle regions was found. When head-up, lesser gradients were found between apex and heart base (J. Appl. Physiol. 23:228, 1967), thus the minimal pressure gradient regions were always cephalad in thorax, independent of body position. Esophageal pressures were always less negative (av. 2 cm H₂O) than pleural and when head-down, gradients were similar only in the heart region. The discrepancy between the vertical pleural pressure gradient and the zero intra-alveolar pressure gradient renders lung function very susceptible to changes in direction and magnitude of the gravitational-inertial force environments.

C. Position dependent regional differences in pericardial pressure

The transmural right and left atrial and ventricular pressures are a major determinant of the degree of diastolic filling of the cardiac chambers and, hence cardiac output. The pressure within the pericardium constitutes the pressure environment of the heart, and transmural cardiac pressures are determined by the difference between intracardiac and pericardial pressures. Changes in pericardial pressure with changes in posture or the gravitational-inertial force environment are, therefore, an important determinant of the cardiovascular responses to these forms of circulatory stress.

Cardiac output, aortic, left and right atrial, pericardial, pleural, and esophageal pressures were recorded from six anesthetized dogs without thoracotomy supported head-up and head-down. A pericardial catheter, #4F, was introduced suprasternally to the apex of the heart and successive records made at six to nine withdrawals of 1 to 1.5 cm towards the base. The catheter was readvanced to the apex of the heart, the animal was inverted and withdrawals repeated. Average vertical distance of cardiac apex from the midthoracic T-6 vertebra was 7.9 cm below when head-up and 3.8 ± 0.7 when head-down. Maximum cardiac vertical dimensions were 9.7 cm and 8.8 ± 0.4 , and horizontal dimensions, 5.7 and 6.1 ± 0.1 . Average pericardial pressures near the heart apex and base were -2.9 ± 0.8 cm H₂O and -10.4 ± 0.05 when head-up, and -9.9 ± 0.7 and -1.8 ± 0.3 when head-down. Mean transmural left and right atrial pressures were 4.0 cm H₂O and 3.4 ± 0.8 when head-up and 5.2 and 2.3 ± 0.5 when head-down, and in each position independent of vertical height

in the cardiac chamber. Average cardiac output was 2.0 and 1.9 ± 0.2 L/minute when head-up and head-down. Elimination of regional differences in transmural pressures by compensated hydrostatic counter pressures in the pericardium minimizes the cardiac effects of changes in direction and magnitude of the gravitational-inertial force environment, as illustrated in Figure 5.

D. Influence of body position on regional pulmonary arterial-venous shunts

It has been demonstrated that the severe degrees of arterial hypoxemia which occur during exposures to acceleration similar to those encountered during the launch and re-entry phases of space flight are due to pulmonary arterial-venous shunts via the dependent portions of the lung (Vandenberg et al., Regional pulmonary arterial-venous shunting caused by gravitational and inertial forces, J. Appl. Physiol., in press). Some degree of the pulmonary atelectasis produced by such exposures may persist in the 1G environment after the exposure is terminated. Furthermore, there is suggestive evidence that significant arterial desaturation may also occur in the 1G environment if body position is maintained unchanged.

Simultaneous determinations of oxygen saturation of blood being withdrawn continuously via cuvette oximeters from aorta, pulmonary artery, left and right dorsal pulmonary veins demonstrate regional differences in oxygenation of pulmonary venous blood in dogs studied without thoracotomy when in supine, left decubitus, and right decubitus positions. During air breathing when supine, the oxygen content of blood from the more dependent pulmonary venous catheter was uniformly lower than systemic arterial and of blood from the more superior vein, and a positive correlation was found between the vertical distance of the pulmonary vein catheter tip below midlung level and the degree of shunt. Desaturation of dependent pulmonary venous blood may occur when breathing 99.6% oxygen, indicating true arterial-venous shunting of 25% or more of this blood. When rotated to the lateral decubitus position so that the more dependent catheter was superior in the chest, oxygen saturation of blood from the now dependent lung occurred. Rotation to the opposite side caused reversal of these changes. The weight of thoracic contents causes pleural pressures to approach zero at dependent surfaces of the lung simultaneously with highly negative values at superior surfaces resulting in a vertical gradient in alveolar size which apparently can extend to collapse in the dependent regions. Change in body position resulted in more long lasting resolution of dependent atelectasis than intermittent positive pressure inflation of the lungs.

E. Effect of gravitational and inertial forces on the regional distribution of pulmonary blood flow in chimpanzees using the radioactive microsphere scintiscanning technic

Prior studies supported by this research grant, described in the April 1, 1968 progress report, have demonstrated that the gravitational force environment decreases blood flow to the superior portions of the lungs while concomitant increases occur, particularly in the midlung regions in dogs. The anatomy of the canine thorax differs considerably from that of man. Therefore, these studies are being repeated in chimpanzees whose thoracic anatomy is closely similar to that of human beings.

The digital computer programs completed to date for this project consist of three major sections: (1) The scanner control program which governs (a) the x and y assembly which sweeps over a 14 x 20 inch scanning plane, and (b) the data sampling, bookkeeping and storage operation routines; (2) The retrieval of the scan data from its multiplexed storage state on digital magnetic tape and the conversion into three-dimensional and counter printer-display formats; (3) The necessary data smoothing, edge contour enhancement, collimator distortion removal prior to the final data output plotting.

The isotope data accumulated in the computer are then displayed in several modes. After the count data has been read from digital magnetic tape (in which each scan in the x-y array is referenced via a file number) and has been rearranged into an x versus y versus count three-dimensional format, two three-dimensional plots are made. One plot views the data from the fourth cartesian quadrant and the second from the third quadrant. In addition, shadow reflection plots of the fourth quadrant three-dimensional data onto the x versus count surface and the y versus count surface are obtained by summing all the data points along their respective x or y lines. Finally, a contour map is created by viewing the three-dimensional plot from above and assigning to each of ten isocount stratifications an alphabetic letter or a blank symbol. Isocount stratification levels are obtained by quantizing the isotope count values into uniform increment levels.

Following the initial display of the data, various forms of data smoothing, distortion removal, and contour edge enhancement are carried out (or are presently being investigated). These fall into three general categories: (1) Data smoothing via a moving, weighted averages technique; (2) Contour edge enhancement via two-dimensional convolution techniques which emphasize a logarithmic data relationship, and (3) Collimator distortion removal obtained via a reconstructing the "true" input data surface contour using a knowledge of the distorted output surface contour and the collimators transfer function. The collimator transfer function is obtained

either by scanning an isotope point source or from a knowledge of the collimator's isoresponse characteristics. Finally, following the above mathematical procedures, a contour map, and/or three-dimensional plot of the data is generated to allow comparison with the original data plots. All of the plotting, smoothing, and data enhancement routines are written in Fortran II language. These techniques are being applied to a study of the effect of the direction and magnitude of gravitational and inertial forces on the distribution of pulmonary blood flow in chimpanzees. An example of a three-dimensional computer generated plot of isotope counts is shown in Figures 6 and 7.

F. Determination of transient changes in stroke volume from the aortic pressure pulse

The aortic pressure pulse method of Warner for measurement of stroke volume is not suitable for beat-to-beat determinations during cardiovascular transients such as arrhythmias or during exposure to rapidly changing accelerative or other types of circulatory stress, since it is based on conditions during which the systolic ejection of a beat is equal to the peripheral runoff (drainage of blood from the aorta which occurs during that cardiac cycle). However, such a method is of considerable value under conditions which precludes acute or chronic implantation of flowmeters. In an attempt to minimize these deficiencies of this pressure pulse technic, a method is being developed which allows determination of a pressure-volume conversion factor for the aorta over a wide range of pressure levels during transient changes in stroke volume. The aortic pressure tracing from the incisura to the onset of the next ejection phase is analyzed by the computer to determine successive time intervals for a given small decrement in pressure throughout the diastolic phase of the beat. This diastolic pressure decay curve, presumably due chiefly to drainage of blood from the aorta to the periphery, is then used to calculate the pressure loss during systole due to flow of blood to the periphery. The total increment in aortic pressure due to systolic ejection, which would have occurred during this beat if no flow of blood out of the aorta had occurred during the period of ventricular ejection, is then calculated. The corrected end-systolic aortic pressure is determined to a major degree by the volume of blood (ventricular stroke volume) which was ejected into the aorta during systole, by the pressure-volume characteristics of the aorta and the end-diastolic pressure in the aorta prior to the ventricular systole under question. The total systolic increment (ΔP_s) is assumed to describe the pressure-volume characteristics of the aorta during systolic ejection under the conditions during which the dye curve was recorded. The calculation of ΔP_s for individual beats incorporates correction for differences in the end-diastolic level of aortic pressure based on the

characteristics and, when necessary, extrapolation therefrom of the pressure decay curve determined during the diastolic phases of preceding and subsequent cardiac cycles.

Beat-to-beat measurements of stroke volumes by this method are being checked against the values obtained simultaneously in intact dogs from electromagnetic flowmeters implanted on the ascending aorta or catheter-tip flowmeters positioned in the aorta from a femoral artery. Values are displayed in the laboratory via a storage oscilloscope connected on-line to the computer. In order to stress the method, dogs with heart block have been used so that sudden very large changes in stroke volume for single and/or successive beats could be produced at will by various combinations of interruption or change in interval of the stimuli driving the atria and ventricles. Such measurements are repeated during large variations in peripheral resistance produced by intra-aortic infusion of acetylcholine or angiotensin II.

G. A study of the timing of left ventricular end-diastole: a prerequisite for accurate measurement of end-diastolic pressure

LVEDP is the intraventricular pressure at the onset of ventricular systole. Although a major determinant of cardiac function, no exact specifications exist for the instant on the LV pressure pulse where this pressure should be measured. The transmission of the atrial systolic pressure wave into the ventricle usually obscures the takeoff point of ventricular systole and hence renders the determination of the exact instant at which ventricular end-diastole occurs equivocal. However, accurate determinations of the timing and pressure of left ventricular end-diastolic is a prerequisite for study of left ventricular function using biplane videoangiography or other techniques.

Experiments have been performed on nine dogs with chronic heart block weighing from 14.5 to 23.5 kg. Atrial and ventricular rates were controlled by coupled electronic pacemakers which allowed variations of A-V intervals from 0-350 milliseconds and omission of a single atrial beat so that the onset of a ventricular beat undisturbed by atrial systole could be measured. Omission of a ventricular beat allowed similar measurement of the intraventricular atrial systolic wave undisturbed by ventricular systole.

On-line calibration of the catheter tip gauges and analysis of the simultaneously recorded left atrial and ventricular pressure pulses were obtained using an analog-to-digital digital-to-analog conversion and Control Data Corporation 3200 digital computer juxtaposed to the laboratory. This system generates via a high-speed incremental plotter (Calcomp) an extended time base high sensitivity plot of left atrial and ventricular pressures on the same base line simultaneously with the

electrocardiogram and the first derivative of the left ventricular pressure pulse.

The results of the study indicate that when a left atrial beat is omitted, two inflection points on the first derivative of the left ventricular pressure occur at a constant time interval after the R wave indicating the onset of left ventricular systole. When a left ventricular beat was dropped and the resulting isolated ventricular left atrial systolic wave subtracted from the previous normal left ventricular pressure pulse, the same presystolic inflection points were observed on the first derivative curve. The initial inflection point represents the earliest detectable pressure rise due to the onset of left ventricular systole and is, therefore, closely contiguous to the instant in the cardiac cycle at which left ventricular end-diastole can be considered to occur. Consequently, it is also considered to be the proper instant at which left ventricular end-diastolic pressure should be measured.

H. Design of low-band pass filters for selective discrimination against high frequency noise in physiologic signals

It is frequently desirable to filter the analog signal obtained from physiological parameters such as ventricular or aortic pressure pulses, in order to remove artifacts due to the movement of the measuring catheter. This type of selective discrimination against noise is particularly desirable when measurements are being made in the presence of external vibration and body movements, as frequently occurs under various conditions of circulatory stress, particularly acceleration. Selective discrimination against noise due to any cause whose frequency is greater than that of the physiological signal under study, is particularly desirable before analog-to-digital conversion of the signal prior to computer analysis. Such filtration reduces the sampling rate required as well as the possibility of introducing aliasing errors during the analog-to-digital conversion process.

The filters required are of the low-band pass variety and often the desired degree of attenuation of frequencies above the band pass may be 24 or more decibels per octave. It is desirable to obtain this degree of discrimination against high frequency components of a signal with no loss of the signal in the pass band; therefore, only active filters were considered.

Originally, the Butterworth type filters were tried; however, the responses of these filters show overshoot and ringing when a step function is inserted. For example, the abrupt decrease in ventricular pressure after the termination of the ejection phase caused a downward overshoot which altered the shape of the diastolic portion of the pressure curve sufficiently to produce unacceptable errors in pressure measurement during diastole.

Perusal of the literature disclosed a filter called the Bessel filter which exhibits no overshoot or ringing when excited by a square-wave regardless of the rate of change of slope. The design parameters of active filters of this type have been worked out so that such filters can be constructed in any physiological or biological research laboratory by anyone familiar with amplifiers and electronic components.

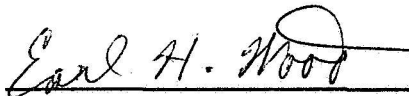
The filter consists of amplifiers, their power supplies, condensers, and resistors. The amplifiers are connected as integrators in analog computer configuration which solves the differential equations in the transfer function characterizing the filter. The roots of the Bessel Polynomials, which are the poles in the complex plane, are used to design the filter. Such filters with cut-off frequencies of 10, 25, and 40 cycles/second, depending on the particular application, have been designed, set up on the analog computer, and their frequency response tested. These filters are used routinely in the laboratory for processing of analog recordings prior to their on-line analysis in the 3200 digital computer.

III. Plans for investigative projects in the period, October 1968 - April 1969:

Work will continue on the projects described herein.

When the biplane roentgen videometry assembly has been completed and tested, in addition to direct studies of ventricular function in restrained animals, it will be used to establish the dynamic relationships between the telemetered output of dimension gauges implanted in the left ventricle and the volume of the left ventricular chamber under a variety of circulatory states.

The ultimate objective of these studies is to obtain dynamic studies of left ventricular function in dogs and chimpanzees during various types of circulatory stress including acceleration and the free-ranging unanesthetized state.


Earl H. Wood, M.D., Ph.D.
September 25, 1968

Publications List

1. Coulam, C. M., J. H. Reed, Jr., and E. H. Wood:
Regional differences in pleural and esophageal pressures in head-up and head-down positions.
Federation Proc. 27:578 (Mar-Apr) 1968.
2. Avasthey, P. and K. G. Wakim (E. H. Wood):
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Federation Proc. 27:446 (Mar-Apr) 1968.
3. Williams, J. C. P., R. E. Sturm, A. G. Tsakiris, and E. H. Wood:
Biplane videoangiography.
J. Appl. Physiol. 24:724-727 (May) 1968.
4. Wood, E. H., R. E. Sturm, and A. G. Tsakiris:
Application of biplane roentgen videometry to dynamic measurement of shape and volume of the left ventricle.
Proc. Summer Workshop sponsored by Council on Basic Science of the American Heart Association, Denver, Colorado (July 24-27, 1967), pp. 10.
5. Tsakiris, A. G., D. E. Donald, R. E. Sturm, and E. H. Wood:
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6. Wood, E. H. and R. E. Sturm:
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7. Tsakiris, A. G., D. E. Donald, R. E. Sturm, and E. H. Wood:
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9. Vandenberg, R. A., J. C. P. Williams, R. E. Sturm, and E. H. Wood:
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10. Reed, J. H., Jr., and E. H. Wood:
Effect of changes in gravitational and inertial force environment on distribution of pulmonary blood flow.
J. Appl. Physiol. - in press.
11. Reed, J. H., Jr., and E. H. Wood:
Effect of body position on distribution of pulmonary blood flow.
J. Appl. Physiol. - in press.

12. Coulam, C. M., P. Avasthey, and E. H. Wood:
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J. App. Physiol. (to be submitted).

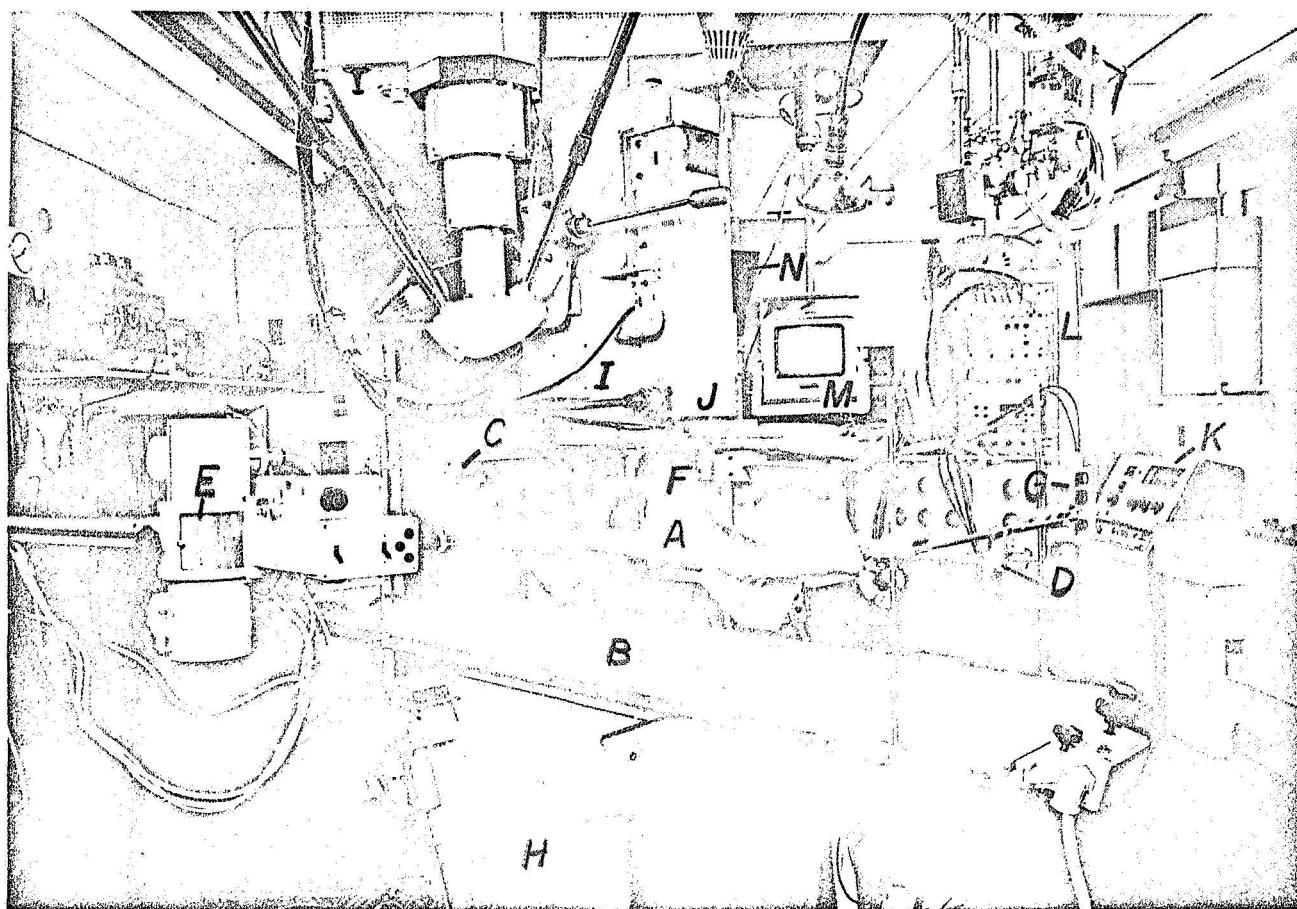


Figure 1

Peripheral equipment used for biplane videometry and videodensitometry.

(A) molded left lateral half-body cast to facilitate optimization and fixation of body position of dog during repetitive biplane videoangiograms. The cast, positioned in this picture to obtain right and left anterior oblique projections of the thorax, is suspended above the fluoroscopic table (B) by iron pipes secured to the cephalad (C) and caudad (D) ends of the cast and aligned on an axis passing through the heart. Each pipe is secured by universal clamp assemblies providing three degrees of freedom so that the body position can be adjusted to bring the long axis of the left ventricle or other structure under study into nearly perpendicular alignment with the axes of the x-ray beams of the respective horizontal and vertical roentgen video systems and also to minimize superposition of high density structures, such as the vertebrae, over the ventricular silhouettes. (E), (F), and (G) designate the positions of the x-ray tube, image intensifier, and image-orthicon camera, respectively, of the horizontal roentgen video system and (H), (I), and (J), the respective components of the vertical system. Accessory

Figure 1 (continued)

equipment: (K) x-ray controls, (L) switching circuits, control and oscilloscope assembly for adjustment of video signal output and relative positions of biplane images on the same video field monitored on television tube (M).

The physiologic parameters of the dog, such as aortic, atrial, and ventricular pressures, respiration, and ECG are recorded on a parallel analog tape, videotape (RCA Model TR2), photokymographic recording assembly in the central electronic data processing and computing facility located three floors below this laboratory. These and other variables are monitored visually on an 8-channel oscilloscope assembly (N) which displays continually either the input signals to or the output from the 14-channel analog tape recorder in the central facility. On-line input to and output from the time-shared CDC 3200 digital computer assembly is obtained by means of a mobile peripheral computer station (not shown) which is juxtaposed to the fluoroscopic table and incorporates immediate computer interrupt and interactive computer-operator implementation of various programs for on-line analysis of hemodynamic and/or videoangiographic data with immediate display of the results in the laboratory in alphanumeric or analog form via a storage oscilloscope and a rapid incremental plotter.

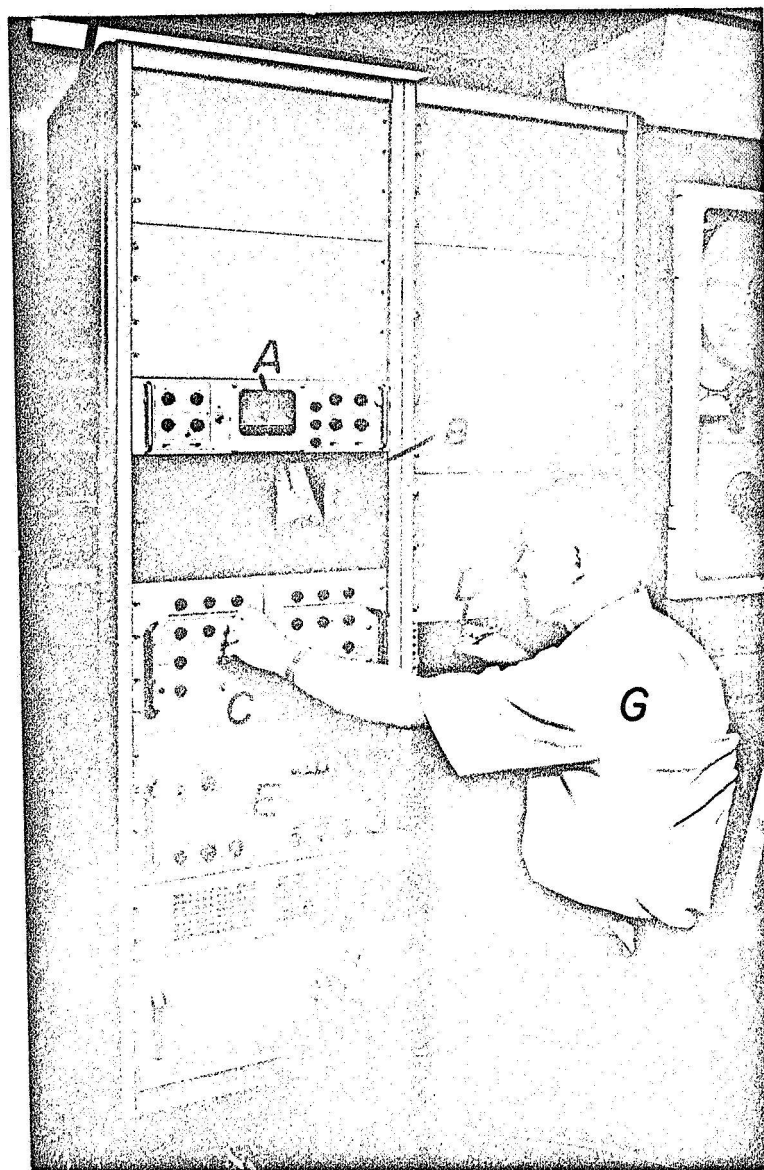


Figure 2

Assembly for masking and operator interactive electronic and manual shading of background structures juxtaposed to the borders of biplane video images of cardiac or other structures (e.g., the left ventricle) under study. This process facilitates electronic recognition of the instants that each horizontal video line encounters and leaves the borders of the cardiac chamber or other structure under study. These recognition points, which occur at a rate of four each 63.5 microseconds during each 60 per second vertical sweep of the video beam, are fed on-line to a juxtaposed CDC 3200 digital computer for on-line computation of the volume and shape of the structure during the intervals between each video field

Figure 2 (continued)

(i.e., 60 times per second). (A) oscilloscope display of biplane video signals, (B) biplane image of cardiac silhouettes being replayed in the stop action (single field) mode from a specially adapted video disc assembly, (C) control circuits for electronic shading of video picture along the vertical and horizontal axes, (D) aperture to video image scan plane of flying-spot scanner assembly for manual masking out of extraneous areas of the video image and shading of the background video signal on which the heart shadow is superimposed, (E) video quantizer assembly for recognition and display (see Figures 3 and 4) of the video signal levels circumscribing the heart shadow, (F) 14-channel analog tape recorder (Ampex) for recording physiologic parameters from peripheral laboratories, such as shown in Figure 1. The model TR-2 videotape, MVR video disc, and photokymographic recorder assemblies (not shown) are juxtaposed to and under control of the individual (G) who interacts with the electronic devices via visual feedback from the video image to obtain the optimum degree of preprocessing of the video signals prior to the input of the border recognition points and other data into the computer for on-line analysis.

ELECTRONIC RECOGNITION OF DIFFERENCES IN ROENTGEN OPACITY
FROM VIDEO IMAGE OF LATERAL PROJECTION OF THORAX
(Dog 18 kg, Morphine-Pentobarbital Anesthesia, End-Expiration)

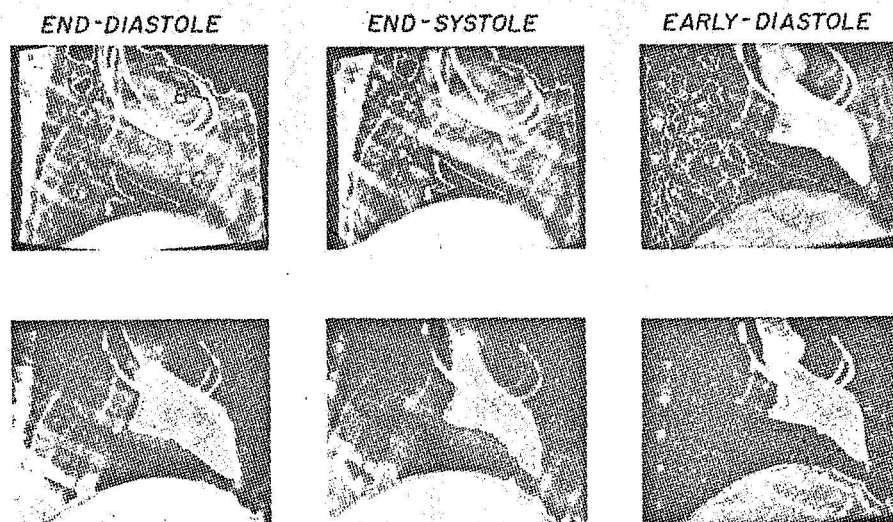


Figure 3

Electronic recognition of differences in roentgen opacity from video images of lateral projection of thorax in an 18 kg dog under morphine-pentobarbital anesthesia.

The roentgenographic exposures were obtained at end-expiration while the heart was being paced at a constant rate of 100 beats/minute via bipolar electrodes A and B at the right atrial-superior caval junction and in the outflow tract of the right ventricle, respectively. The atrial-ventricular stimulus interval was 80 msec. Recordings of left ventricular pressures and injections of the contrast medium (6 ml of 69% renovist) into the left ventricle were made interchangeably via catheter C. Catheters were also positioned without thoracotomy with their tips in the pulmonary artery (upper left), pulmonary vein (center), and thoracic aorta (left). The pictures were synchronized with the electrocardiogram to obtain the exposures from left to right: at end-diastole, end-systole, and the early diastolic phase of the first cardiac cycle after completion of injection of the contrast medium.

Each recognition point is displayed as a bright spot at the respective point or points on each horizontal line at which the selected level of video signal (roentgen opacity) was encountered. Recognition of portions of the external borders of the heart prior to injection of contrast media along with other areas of equal contrast in the image is illustrated in the two left upper panels, and just

Figure 3 (continued)

after completion of the injection in the right upper panel. This latter exposure allows assessment of the thickness of the ventricular wall. Note the differences in area of the left ventricular silhouette at end-diastole and end-systole in the two left lower panels and the onset of filling of the ventricle with non-dyed blood via the mitral valve, highlighted by the three contrast level lines, in the lower right panel.



Figure 4

Superposition of silhouettes of the left ventricle obtained at end-diastole and end-systole. Conditions are the same as for Figure 3.

Note that contraction of the ventricle produced relatively little change in length of its longitudinal axis, and that the major factor causing the decrease in area of the silhouette during systole was a decrease in transverse diameters. The left atrial margin of the mitral valve is silhouetted as the lower two-thirds of the left margin of the ventricle. No regurgitation is discernible. Opening of this valve is visualized in the right panels of Figure 1.

SIMULTANEOUS PERICARDIAL, RIGHT ATRIAL, AND RIGHT ATRIAL TRANSMURAL PRESSURES IN DIFFERENT BODY POSITIONS (6 Dogs, Morphine - Pentobarbital Anesthesia)

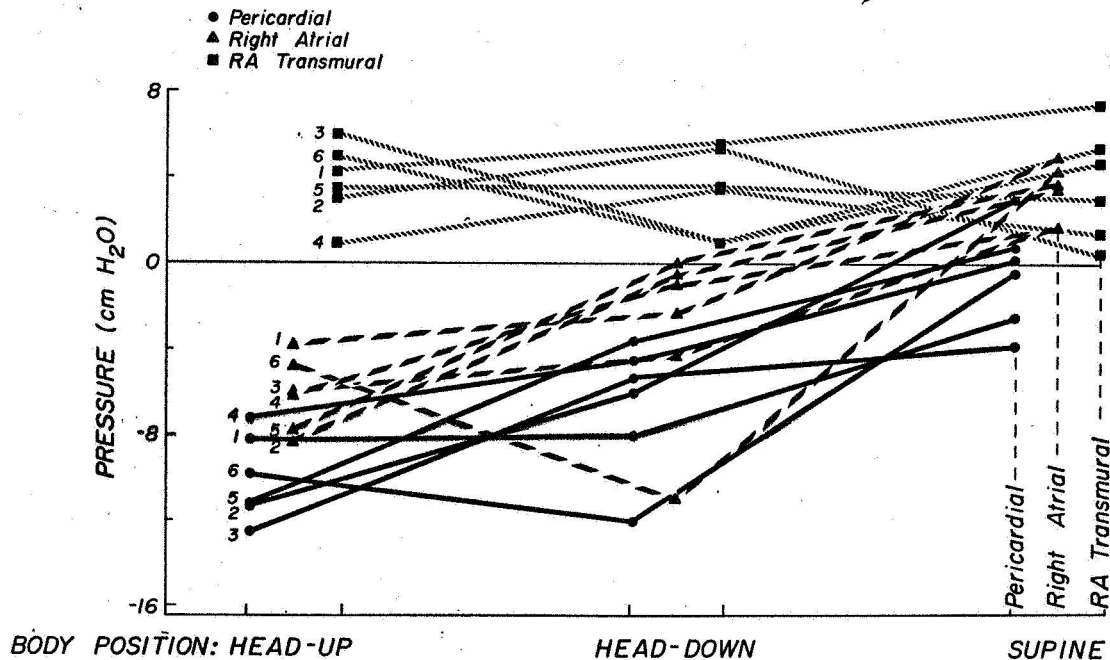


Figure 5

Changes in mean end-expiratory pericardial and right atrial pressures with change in body position. Note that the considerable decrease in right atrial pressure (zero reference point, middle of 6th thoracic vertebra) which occurred when the dogs were tilted head-up, was compensated for by a similar decrease in intrapericardial pressure so that there was no systematic change in the transmural (filling) pressure in the right ventricle. As would be expected from this finding, changes in stroke volume and cardiac output were small (see text).

COMPUTER GENERATED THREE-DIMENSIONAL PLOT
OF COUNTS RECORDED IN A SCANNING PLANE
(Radiation Source: 25μ curies I^{131} in 5 mm Capsule)

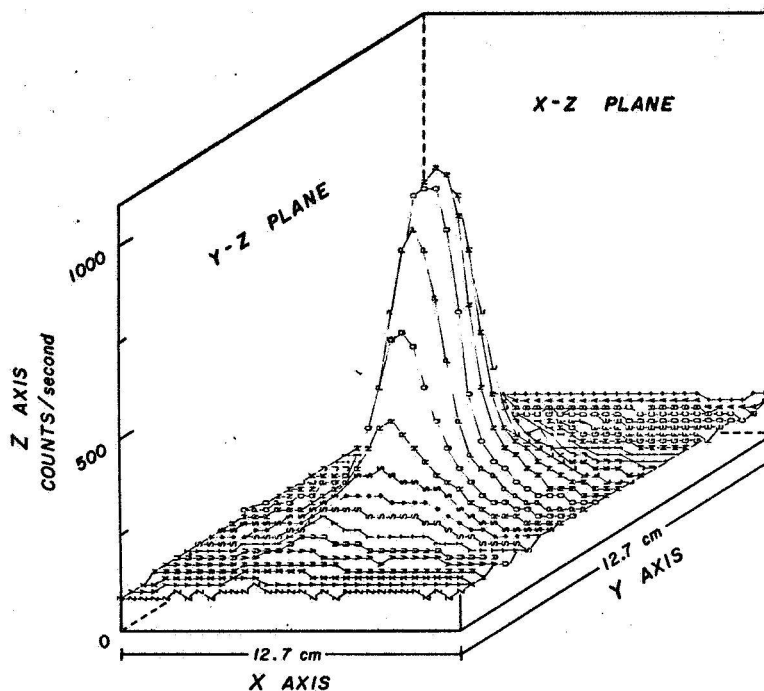


Figure 6

Three-dimensional plot of isotope counts obtained by a computer controlled scintillation scanner assembly. Each letter represents a count value and the same letters (connected by lines) show all the count values obtained during a single traverse of the scanning head across the scanning plane (see text for discussion).

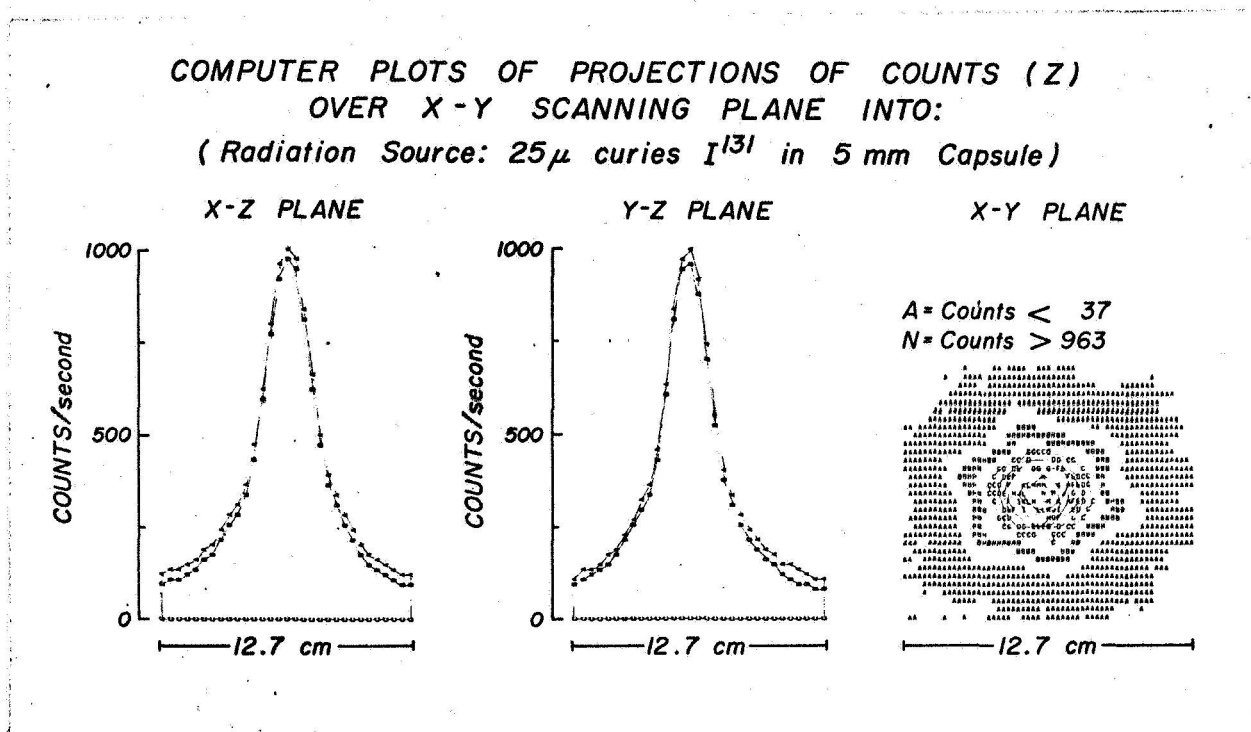


Figure 7

Computer plots of projections of three-dimensional display, shown in Figure 1, onto the X-Z, Y-Z, and X-Y planes, respectively. See Figure 1 for orientation of these planes.